The role of two-particle processes in deep inelastic scattering of electrons by nuclei

S. I. Nagornyĭ, É. L. Kuplennikov, and E. V. Inopin
Physicotechnical Institute of Low Temperatures, Ukrainian Academy of Sciences

(Submitted 22 April 1980)
Pis'ma Zh. Eksp. Teor. Fiz. **31**, No. 12, 784–788 (20 June 1980)

Numerical calculations of the contribution of two-particle knockout mechanisms $(e,e'd)$ and $(e,e'NN)$ in deep inelastic scattering of electrons by a carbon nucleus were performed. It is shown that these processes can give a significant contribution to the scattering cross section. Allowance for the contributions of two-particle mechanisms made it possible to describe for the first time the intermediate region in the energy spectrum of the $^{12}C(e,e')$ reaction between the peaks by using the quasi-elastic and 3–3 resonance.

PACS numbers: 25.30.Cg

The study of deep inelastic scattering of electrons by nuclei holds one of the leading places in high energy nuclear physics because of its relative simplicity of measurement, known type of interaction, unambiguity and high information yield.

Two maxima can be observed in the spectra of scattered electrons in the region of large energy transfer ω. The first one, which is situated in the region $\omega \sim \mathbf{q}^2/2M^*$ ($\mathbf{q}$ is the momentum transfer and M^* is the effective mass) and called the quasi-elastic maximum, is interpreted as quasi-free electron scattering by individual nucleons and the second one, which corresponds to the 3–3 resonance, is interpreted as the electroproduction of π mesons by nucleons.

A comparison of the experimental data with the predictions of theoretical calculations performed for a whole series of nuclei ranging from ^3He to ^{208}Pb,[1] showed that a satisfactory agreement can be obtained between the cross section at the maximum and the width and location of the quasi-elastic peak by changing the parameters of the nuclear models. At the same time, none of the existing models can describe the intermediate region of the cross section minimum between the quasi-elastic peak and the 3–3 resonance where a systematic discrepancy between the theory and experiment was observed.

Analysis of the data within the context of different theoretical models, including exact calculations performed for a three-nucleon system ^3He nuclei[1] showed that this discrepancy is apparently not connected with the use of insufficiently real interaction potentials.

In our opinion, allowance for the short-range correlations and for the finite width of the hole states does not change the overall picture, since their influence is negligible.[2,3]

In this investigation we assumed that more complex mechanisms such as two-particle knockout mechanisms $(e,e'd)$ and $(e,e'NN)$ can play a dominant role in the region beyond the quasi-elastic peak.[4] To describe the spectra of inelastically scattered electrons in the intermediate energy region, we must sum a whole series of elementary processes: $(e,e'N)$, $(e,e'\pi)$, $(e,e'd)$ and $(e,e'NN)$.

Although the contribution of the $(e,e'd)$ process to the cross section of deep inelastic scattering of electrons by a carbon nucleus[4] calculated by us partially improved the situation, it proved to be insufficient for a complete agreement between the theory and experiment in the region of large $\mathbf{q}^2$. In view of this, we calculated the contributions of the $(e,e'NN)$ processes. The yield of the nucleon-nucleon pairs was calculated on the basis of a direct correlation knockout mechanism.[5] The cross section of the $A\,(e,e'2N)$ reaction can be represented in the form

$$d\sigma_c = \frac{\pi}{2E_i E_f}\left(\frac{4\pi e^2}{q^2}\right)^2 R_c(q)\,\rho_c(E_f);\ \ \rho_c(E_f) = (2\pi)^{-9} 2E_f^2 MP\, d^3\mathbf{k}\, dE_f \times d\Omega_f\, d\Omega_{\mathbf{p}}, \tag{1}$$

where $|c\rangle$ is the state of a free nucleon pair $|c\rangle = |NN\rangle = |\mathbf{p},\mathbf{k},\xi\rangle$, $\mathbf{p}$ is their c.m. momentum (which is determined by the energy conservation law), $\mathbf{k}$ is the relative momentum, and ξ is a set of spin-isospin quantum numbers. All the remaining notations were described in Ref. 4. Using the relations (3) and (5) in Ref. 4, expressing $I_{\mu\delta}^{(x=2)}(q)$ from Eq. (3) through a two-particle density matrix $\Gamma(\mathbf{r}_1,\mathbf{r}_2\xi;\mathbf{r}_1',\mathbf{r}_2'\xi')$ when the indices coincide, and using the methods described in the theory of photonuclear reactions,[6,7] we can calculate the cross section (1). Since the $|c\rangle$ state has not been established in the deep inelastic scattering of electrons by nuclei, $d\sigma_c$ must be summed over all possible c's in order to obtain the sought-for value of $\sigma(e,e')$:

$$\sigma(e,e') = \sum_c d\sigma_c\,. \tag{2}$$

The integration in Eq. (2) was performed analogous to that in Ref. 7. The interaction in the final state was disregarded.

The results of numerical calculations showed that the contributions of the $(e,e'd)$ and $(e,e'NN)$ processes are comparable in order of magnitude. If, however, the contribution of the $(e,e'd)$ reaction decreases rapidly with increasing $\mathbf{q}^2$, then the contribution of the $(e,e'NN)$ processes will have the opposite effect.

Our estimates of the total contribution of the "elementary" $(e,e'NN)$ and $(e,e'd)$ processes and also of the single-particle mechanism for $(e,e'N)$ knockout and $(e,e'\pi)$ meson production showed that the intermediate region in the (e,e') reaction can be described satisfactorily only at small scattering angles ($|\mathbf{q}| \lesssim 1.5\mathrm{F}^{-1}$). The deviation of the total theoretical curve from the experimental points increased systematically with increasing recording angle of the electron.

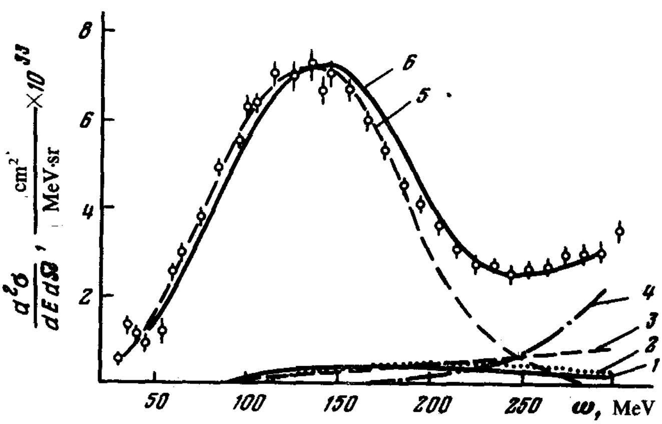

FIG. 1. Dependence of the differential cross section for scattering of 500-MeV electrons by a carbon nucleus on the energy of the recorded electron. The scattering angle is 60°. Curves 1–6 are explained in the text. The radius of short-range correlations was chosen to be 0.75 F^{-1}.

Analysis of the observed deviation of different spectra of a carbon nucleus showed that it is apparently attributable to the knockout processes of *np* pairs due to charge-exchange meson current whose role increases with increasing $\mathbf{q}^2$.[8]

According to Ref. 9, an allowance for this effect makes it possible to eliminate the discrepancy between the theory and experiment in the region of large scattering angles of electrons.

Figure 1 shows the results of numerical calculations of the energy spectrum for the $^{12}C(e,e')$ reaction and the experimental data.[10] The combined theoretical curve 6 includes the following processes: 1 and 2—$(e,e'd)$ and $(e,e'NN)$ contributions (our calculation), 3—contribution of the exchange meson currents,[9] 4—contribution of meson electroproduction,[9] and 5—quasi-free nucleon knockout mechanism.[9] The overall curve was normalized at the maximum of the quasi-elastic peak. We can see that it is in good agreement with the experiment.

The numerical calculations show that the role of two-particle mechanisms is large (about 20%) even in the maximum of the quasi-elastic peak. Therefore, if this mechanism is disregarded in the fitting of theoretical curves to the experimental data, as was done earlier, then the nuclear parameters obtained from the analysis will be distorted.

The result obtained by Glaw *et al.*,[11] who "succeeded" in describing the entire measured spectrum of the deep inelastic scattering of electrons by a ^{12}C nucleus on the basis of only the single-particle mechanisms, seems very odd in our opinion. Such agreement could be accounted for at very high momentum transfer, because under these conditions the quasi-elastic and 3–3 resonance peaks overlap strongly and shadow the effects due to two-particle mechanisms (the intermediate region in this case almost disappears).

The results of this investigation can be briefly summarized as follows: 1) We were able to describe for the first time the intermediate region in the energy spectra of inelastically scattered electrons between the peaks by using the quasi-elastic and 3–3 resonance; 2) it is shown that the large cross section in the intermediate region can be accounted for only by including the two-particle mechanisms, in contrast to Ref. 11; 3) the location, width and the absolute cross section of the (e,e') reaction in the region of the quasi-elastic peak depends on the contribution of the two-particle mechanisms; 4) the nuclear-structure parameters extracted from an analysis of the experimental data by fitting the cross sections calculated solely on the basis of a single-particle, quasi-free mechanism are slightly distorted and require the introduction of corrections.

[1]T. de Forest, Elektromagnitnye vzaimodeistviya yader pri malykh i srednikh énergiyakh (Electromagnetic Interactions of Nuclei at Low and Intermediate Energies), Nauka, Moscow, 1979.
[2]C. Cioffi Degli Atti, Let. Nuovo Cim. **1**, 590 (1971).
[3]V. V. Gorchakov, A. A. Goi, and B. P. Regnik, Yad. Fiz. **22**, 987 (1975) [Sov. J. Nucl. Phys. **22**, 514 (1975)].
[4]É. L. Kuplennikov, S. I. Nagornyi, and E. V. Inopin, Yad. Fiz. **30**, 1515 (1979) [Sov. J. Nucl. Phys. **30**, 785 (1979)].
[5]Y. N. Srivastava, Phys. Rev. **B135**, 612 (1964).
[6]K. Gottfried, Nucl. Phys. **5**, 557 (1958).
[7]S. Fujii, Nuovo Cim. **25**, 995 (1962).
[8]J. A. Lock and L. L. Foldy, Ann. of Phys. **93**, 335 (1975).
[9]T. W. Donnelly *et al.*, Phys. Lett. **76B**, 393 (1978).
[10]R. R. Whitney *et al.*, Phys. Rev. **9C**, 2230 (1974).
[11]U. Glaw *et al.*, Phys. Lett. **89B**, 44 (1979).